## Can HERA see an $eu \rightarrow ec$ signal of a virtual leptoquark?

Miriam Leurer

Department of Nuclear Physics, The Weizmann Institute, Rehovot 76100, Israel

(Received 12 June 1992)

Virtual leptoquarks could be detected at the DESY ep collider HERA through some nonstandard effects. Here we explore the possibility that virtual leptoquarks could be discovered via  $eu \rightarrow ec$  scattering, assuming an integrated luminosity of 200 pb<sup>-1</sup> and charm identification efficiency of 1%. We study the implications of low-energy data for the leptoquark couplings and find that the most relevant bound for the HERA cross sections comes from inclusive  $c \rightarrow e^+e^- + any$ . This bound implies that the  $eu \rightarrow ec$  cross sections for virtual leptoquarks are just too small for observation of the signal. With an improvement by a factor of  $\sim 2$  on the luminosity or on the charm identification it could be possible to see virtual leptoquarks with maximum couplings up to  $\sim 1.5-2$  TeV. However, the prospects for discovering the virtual particles if their couplings are somewhat below present bounds are very dim. We point out that this cross section could be very large for leptoquarks lighter than HERA's kinematical limit, and if such a leptoquark is discovered we recommend searching for a possible  $eu \rightarrow ec$  signal. Our results may also serve as an update on the maximum cross sections for leptoquark-mediated  $eu \rightarrow \mu c$  scattering.

PACS number(s): 12.15.Cc, 13.60.Hb, 14.80.Er

It is well known that the DESY ep collider HERA is an ideal machine for the discovery of low-lying leptoquarks. Such particles, if their mass lies below HERA's kinematical limit and if their coupling to fermions are not particularly small, are expected to manifest themselves as peaks in the x distribution of the ep cross section.

To extend the leptoquark search at HERA beyond the center-of-mass energy, one has to study nonstandard effects that would be induced by such virtual particles. In the past, the possibility that a virtual leptoquark could be discovered if it induced  $eu \rightarrow \mu c$  scattering has been studied [1]. This process would look at HERA as  $ep \rightarrow \mu + any$ , and, since the muon signal is so prominent, it could enable one to penetrate the TeV scale. In this paper we will study the process  $eu \rightarrow ec$ . Its signature is not as prominent—it will look at HERA as  $ep \rightarrow ec + any$  and to be able to distinguish such a signal one will need to identify the charm quark.

The best charm identification method available now to the ZEUS collaboration at HERA is observing a charged  $D^*$  through the decay chain  $D^{*+} \rightarrow D^0 \pi^+ \rightarrow K^- \pi^+ \pi^+$ [2]. Unfortunately, the efficiency is low. Less than 50 % of the charm quarks will hadronize to a charged  $D^*$ ; the branching ratio of the first decay in the chain is 55%, and of the second 3.7% [3]. So, even before taking into account the deficiencies of the detector, the efficiency cannot exceed 1%. Assuming an integrated luminosity of 200 pb<sup>-1</sup> we will therefore request that the  $eu \rightarrow ec$  cross section be at least 1 pb.

The paper is organized as follows. First, we review the standard model backgrounds and the cuts that are necessary to control them [2]. Then we consider the possibility that an  $eu \rightarrow ec$  scattering could be induced by nonstandard physics that is *not* leptoquarks, and find that the effects of such physics are completely negligible. Next we discuss low-energy data and the bounds implied on leptoquarks couplings. We use these bounds to calculate the maximally allowed  $ep \rightarrow ec + any cross section as a func-$ 

tion of the leptoquark mass. We explain why our results are also a significant update on the  $ep \rightarrow \mu + any$  cross section. Conclusions follow.

The most significant standard model backgrounds originate from scattering of the electron on charm quarks in the proton sea, and from photon-gluon fusion leading to the creation of  $c\overline{c}$  and  $b\overline{b}$  pairs. Both backgrounds can be significantly suppressed by cuts on  $x (x > x_{\min})$  and t $(|t| > Q_{\min}^2)$  [2], while leptoquark signals are not much affected by these cuts [4]. We also note that  $eu \rightarrow ec$ scattering is allowed in the standard model at one loop, but the cross section is suppressed both by a loop suppression factor  $(\alpha_W/4\pi)^2$  and by a Glashow-Iliopoulos-Maiani (GIM) suppression factor  $|\sum_{i} V_{ui} V_{ci}^* m_i^2 / M_W^2|^2$  (here i = d, s, or b, and V is the Cabibbo-Kobayashi-Maskawa matrix). These suppressions make the standard model  $eu \rightarrow ec$  cross section far too small to have any effect in HERA. We therefore conclude that standard model backgrounds can be controlled by appropriate cuts on x and t.

Addressing the question as to whether  $eu \rightarrow ec$  scattering at HERA could be induced by nonstandard physics other than leptoquarks, we will make the simplifying assumption that such a nonstandard process occurs at the tree level and is mediated by a scalar or vector boson in the *t*, *s*, or *u* channel. A boson in the *t* channel is neutral, and induces flavor-changing neutral currents (FCNC's) in the quark sector. Such a boson could even be the *Z* itself, with some nonstandard couplings. Bosons in the *s* or *u* channels carry  $\frac{1}{3}$  or  $\frac{5}{3}$  units of electromagnetic charge and are leptoquarks. Let us investigate the *t*-channel bosons. Since they induce FCNC's in the quark sector there are strong bounds on their couplings. The experimental bound on  $D^0$ - $\overline{D}^0$  mixing [3] implies that

$$\frac{(g^q)^2}{M^2} \lesssim 10^{-7} G_F , \qquad (1)$$

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where  $g^q$  is the flavor-changing coupling to the quarks and M is the boson mass. The coupling to the electron is certainly bounded by

$$\frac{(g^e)^2}{M^2} \le \frac{G_F}{\sqrt{2}} \ . \tag{2}$$

The bounds (1) and (2) imply that the  $eu \rightarrow ec$  cross section at HERA will be  $\sim (10^{-6})$  pb; that is, there will be no events. We therefore conclude that an  $eu \rightarrow ec$  scattering, if seen, must be induced by leptoquarks.

When discussing the leptoquarks, we will, for convenience, refer to the charge  $\frac{1}{3}$  particles. All the bounds on the coupling constants apply to the charge  $\frac{5}{3}$  particles as well (when interchanging quarks and antiquarks), and the final results, the maximum cross sections in HERA, will be presented separately for the two kinds of particles.

We start by writing down the most general interaction Lagrangian for the vector and scalar leptoquark:

$$\mathcal{L}_{int} = [\overline{e}^{c} \gamma^{\mu} (g_{L}^{c} P_{L} + g_{R}^{u} P_{R}) u + \overline{e}^{c} \gamma^{\mu} (g_{L}^{c} P_{L} + g_{R}^{c} P_{R}) c] V_{\mu} , \qquad (3)$$

$$\mathcal{L}_{int} = [\overline{e}^{c}(g_{L}^{u}P_{L} + g_{R}^{u}P_{R})u + \overline{e}^{c}(g_{L}^{c}P_{L} + g_{R}^{c}P_{R})c]\Phi .$$
(4)

We did not impose  $SU(2)_W$  gauge invariance. Generally, since  $SU(2)_W$  is a broken symmetry, it does not forbid any of the interaction terms but rather implies that some other, related interactions exist. For example,  $\Phi$  is a mixture of an  $SU(2)_W$  singlet and a component of a triplet. Its interactions are related to those of the other members of the triplet. The interactions related to (3) and (4) by  $SU(2)_W$  were discussed in [5], [6], [7], and [1], and in the following we will show that they have *no* implications for our process.

Next, we write down the  $eu \rightarrow ec$  cross section for the vector and scalar leptoquarks:

$$\frac{d\sigma_{V}}{dt} = \frac{1}{16\pi} \frac{1}{(s - M_{V}^{2})^{2} + M_{V}^{2} \Gamma_{V}^{2}} \left\{ \left( |g_{L}^{u}|^{2} |g_{L}^{c}|^{2} + |g_{R}^{u}|^{2} |g_{R}^{c}|^{2} \right) \left[ \frac{u}{s} \right]^{2} + \left[ \left( |g_{L}^{u}|^{2} |g_{R}^{c}|^{2} + |g_{R}^{u}|^{2} |g_{L}^{c}|^{2} \right) \right] \left[ \frac{t}{s} \right]^{2} \right\} \\
= \frac{1}{16\pi} \frac{1}{(s - M_{V}^{2})^{2} + M_{V}^{2} \Gamma_{V}^{2}} \left[ g_{V}^{4} \left[ \frac{u}{s} \right]^{2} + \tilde{g}_{V}^{4} \left[ \frac{t}{s} \right]^{2} \right] , \qquad (5)$$

$$\frac{d\sigma_{S}}{dt} = \frac{1}{64\pi} \frac{1}{(s - M_{S}^{2})^{2} + M_{S}^{2} \Gamma_{S}^{2}} \left[ |g_{L}^{u}|^{2} + |g_{R}^{u}|^{2} \right] \left( |g_{L}^{c}|^{2} + |g_{R}^{c}|^{2} \right) \\
= \frac{1}{64\pi} \frac{1}{(s - M_{S}^{2})^{2} + M_{S}^{2} \Gamma_{S}^{2}} \left[ g_{S}^{4} + \tilde{g}_{S}^{4} \right] . \qquad (6)$$

We have defined g and  $\tilde{g}$  where  $g^4 = |g_L^u|^2 |g_L^c|^2 + |g_R^u|^2 |g_R^c|^2$  and  $\tilde{g}^4 = |g_L^u|^2 |g_R^c|^2 + |g_R^u|^2 |g_L^c|^2$ . Note that only these two combinations of the coupling constants are relevant for HERA.  $M_V$  and  $M_S$  are the masses of the vector and scalar leptoquarks and  $\Gamma_V$  and  $\Gamma_S$  are the widths.

Here we should note that the experimentalists will hunt for charm and anticharm with equal enthusiasm and efficiency. We therefore always sum the cross sections of  $ep \rightarrow ec + any$  and of  $ep \rightarrow e\overline{c} + any$ . At the quark level we are interested in  $eu \rightarrow ec$  and in  $e\overline{u} \rightarrow e\overline{c}$ . Looking at Figs. 1(a) and 1(b), which describe the two scattering processes for the charge  $\frac{1}{3}$  and  $\frac{5}{3}$  leptoquarks, one notes that the leptoquarks always run in either the s or the u channel. The s-channel cross sections are given by (5) and (6). To get the u-channel cross sections from those formulas write  $d\sigma/dt = (1/16\pi^2 s^2)|\mathcal{M}|^2$ , and interchange the variables u and s in  $|\mathcal{M}|^2$ . Obviously, for both scattering processes, the only relevant combinations of coupling constants are g and  $\tilde{g}$ .

Our next task is to place low-energy bounds on the g and  $\tilde{g}$  couplings. In this case,  $D^0 \cdot \overline{D}^0$  mixing does not give a useful bound. The mixing now occurs through a box diagram which is, of course, suppressed being one loop instead of tree level, and in addition could be suppressed due to some GIM-like mechanism which could be at work among the leptons.

Next we look at bounds coming from  $D^0$  decay to  $e^+e^-$ . The relevant effective interaction for vector leptoquarks is

$$\mathcal{L}_{\text{eff}} = \frac{1}{M_{V}^{2} + iM_{V}\Gamma_{V}} \bar{u}\gamma^{\mu} [(g_{L}^{u})^{*}P_{L} + (g_{R}^{u})^{*}P_{R}] e^{c} \bar{e}^{c}\gamma_{\mu} [(g_{L}^{c})P_{L} + (g_{R}^{c})P_{R}] c .$$
(7)

In order to get the  $D^0 \rightarrow e^+e^-$  decay rate, we Fierztransform  $\mathcal{L}_{\text{eff}}$ . Then, comparing the result with the Particle Data Group (PDG) bound [3] ( $B < 1.3 \times 10^{-4}$ ) we find

$$E \frac{\tilde{g}_{V}^{4}}{M_{V}^{4} + M_{V}^{2} \Gamma_{V}^{2}} < 3 \times 10^{-4} G_{F}^{2} , \qquad (8)$$

where E > 1 is an enhancement factor: It is the ratio of  $\langle \overline{D}^0 | \overline{u} \gamma_5 c | 0 \rangle \langle 0 | \overline{u} \gamma_5 c | D^0 \rangle$  to



FIG. 1. Feynman diagrams for  $eu \rightarrow ec$  scattering and  $e\overline{u} \rightarrow e\overline{c}$  scattering via a charge  $\frac{1}{3}$  leptoquark (a) and a charge  $\frac{5}{3}$  leptoquark (b).

 $\langle \overline{D}^0 | \overline{u} \gamma^{\mu} \gamma_5 c | 0 \rangle \langle 0 | \overline{u} \gamma_{\mu} \gamma_5 c | D^0 \rangle$ . Repeating the same procedure for the scalar leptoquarks we find

$$E\frac{\tilde{g}_{S}^{4}}{M_{S}^{4}+M_{S}^{2}\Gamma_{S}^{2}} < 4.8 \times 10^{-3}G_{F}^{2} .$$
<sup>(9)</sup>

To get a bound on the g couplings, we use the CLEO bound  $B(c \rightarrow e^+e^- + any) < 2.2 \times 10^{-3}$  at 90% C.L. [8] (see also [9]). Using the effective Lagrangian (7), this bound implies

$$\frac{g_V^4 + \tilde{g}_V^4}{M_V^4 + M_V^2 \Gamma_V^2} < 0.088 G_F^2 .$$
 (10)

Similarly, one finds

$$\frac{g_S^4 + \tilde{g}_S^4}{M_S^4 + M_S^2 \Gamma_S^2} < 0.18G_F^2 . \tag{11}$$

Note that the bounds (8) and (9) on  $\tilde{g}^4$  are much stricter than the bounds (10) and (11) on the sum  $g^4 + \tilde{g}^4$ . Since we are interested in the case where the bounds are saturated (so that the HERA cross sections are as large as could be), the  $\tilde{g}$  couplings are negligible. This holds for the whole leptoquark mass range that is of interest for us (up to  $\sim 2-3$  TeV).

We now comment on a large list of bounds derived in [5], [6], and [1]. Some of these bounds arise directly from our interaction Lagrangians (3) and (4), which induce new contributions to processes and quantities that are strongly suppressed in the standard model, i.e., to  $\pi^0 \rightarrow e^+ e^$ decay and to g-2 and the electric dipole moment of the electron. The other bounds arise when one takes into account the  $SU(2)_W$  symmetry, which implies the existence of other interactions, related to our Lagrangians. These extra interactions induce new contributions to nuclear  $\beta$ decay, to  $\pi^+ \rightarrow e^+ v$ ,  $K^+ \rightarrow e^+ v$ ,  $K^+ \rightarrow \pi^+ v \overline{v}$ , and  $K^0 \rightarrow e^+e^-$  decays. It turns out that all these bounds, whether derived directly from our Lagrangians or by using the  $SU(2)_W$  symmetry to find related interactions, apply to combinations of the coupling constants of the form  $g_L^i g_L^i$  or  $g_L^i g_R^i$  (where i, j = u or c). We may satisfy all of them by suppressing the left-handed (LH) couplings  $g_L^u$ and  $g_L^c$ . There is no need to suppress the right-handed (RH) couplings. In other words, all these bounds may apply to  $\tilde{g}$  (which we anyway decided to neglect) but not to g.

Summarizing the bounds on the leptoquark couplings, there are only two combinations of the coupling constants that are relevant for the HERA cross sections: gand  $\tilde{g}$ . The bounds on  $\tilde{g}$  are far stricter and we therefore neglect terms proportional to these coupling constants. The *only* bounds on the g couplings come from inclusive  $c \rightarrow e^+e^- + any$  decay and they are given in (10) and (11).

To be able to use the bounds (10) and (11) we still need an estimate for the leptoquarks widths. Clearly, the smaller the widths the larger the cross sections allowed by the bounds. We do not know the full width of the leptoquark, but we know its partial width to two decay channels: *eu* and *ec*. Since we wish the width to be as small as possible we will assume that there are no other decay modes. Then, using the interaction Lagrangians (3) and (4), we calculate the widths

$$\Gamma_V = \frac{1}{24\pi} (|g_L^u|^2 + |g_R^u|^2 + |g_L^c|^2 + |g_R^c|^2) M_V$$
(12)

and

$$\Gamma_{S} = \frac{1}{16\pi} (|g_{L}^{u}|^{2} + |g_{R}^{u}|^{2} + |g_{L}^{c}|^{2} + |g_{R}^{c}|^{2})M_{S} .$$
(13)

To maximize the cross section of  $eu \rightarrow ec$  scattering, we should make the partial width of the eu channel equal to that of the ec channel. Then

$$\Gamma_V = \frac{1}{12\pi} \sqrt{g_V^4 + \tilde{g}_V^4} M_V , \qquad (14)$$

$$\Gamma_S = \frac{1}{8\pi} \sqrt{g_S^4 + \tilde{g}_S^4} M_S . \tag{15}$$

If we now saturate the bounds, neglect the  $\tilde{g}$  couplings, and use the last formulas for the widths, we can express all the quantities that are relevant to the HERA cross sections as functions of the leptoquark masses. The maximal  $g_V$  and  $g_S$  are given by

$$g_V^4 = 0.088 G_F^2 M_V^4 / [1 - 0.088 G_F^2 M_V^4 / (12\pi)^2], \qquad (16)$$

$$g_S^4 = 0.18G_F^2 M_S^4 / [1 - 0.18G_F^2 M_S^4 / (8\pi)^2] .$$
 (17)

A graphical description of the maximal  $g_V^2$  and  $g_S^2$  is given in Fig. 2. Note that  $g_V^2$  reaches  $4\pi$  at  $M_V \approx 1.85$ TeV and  $g_S^2$  at  $M_s \approx 1.5$  TeV. From these masses up, we do not saturate the bounds (10) and (11), but rather fix the maximal coupling constants at  $4\pi$ .

Once  $g_V$  and  $g_S$  are given as functions of the leptoquark masses, we may substitute them in (14) and (15) and get the widths as functions of the masses. We then substitute the coupling constants and the widths into the cross-section formulas (5) and (6) and get the maximum cross sections for each leptoquark mass.

To get the  $ep \rightarrow ec$  + any cross section we have to convolute the  $eu \rightarrow ec$  cross section with the structure function of the up quark:



FIG. 2. Maximum allowed values for the leptoquark coupling constants. The solid line describes  $g_V^2$  and the dashed one  $g_S^2$ .

$$\frac{d^2\sigma}{dx\,dt}(ep \to ec) = f_u(x,\hat{s})\frac{d\hat{\sigma}}{dt}(eu \to ec) , \qquad (18)$$

where x is the fraction of the proton momentum carried by the up quark and  $\hat{s}$  is xs (with  $\sqrt{s} = 314$  GeV being HERA's center-of-mass energy).  $f_u(x,\hat{s})$  is the up-quark structure function and  $(d\hat{\sigma}/dt)(eu \rightarrow ec)$  is the  $eu \rightarrow ec$ differential cross section when the center-of-mass energy of the eu system is  $\hat{s}$ . The structure functions we use are an approximation to Eichten-Hinchliffe-Lane-Quigg (EHLQ) set 2 [10].

We also have to take into account the cuts we use to get rid of the standard model backgrounds. The loosest cuts we employ here are  $x > x_{\min} = 0.1$  and  $|t| > Q_{\min}^2 = 1000 \text{ GeV}^2$ . Under these cuts, the two types of backgrounds are reduced to 3-4 pb each. Another set of cuts we consider is  $x_{\min} = 0.2$ ,  $Q_{\min}^2 = 5000 \text{ GeV}^2$ . Under these, each background reduces to  $\sim 0.1 \text{ pb}$ .

Our results for the charge  $\frac{1}{3}$  vector and scalar leptoquarks are presented in Fig. 3(a). The mass range



FIG. 3. Maximum  $ep \rightarrow ec + any$  cross sections for charge  $\frac{1}{3}$  leptoquarks, with the looser set of cuts  $(x > 0.1, |t| > 1000 \text{ GeV}^2)$ , and with the stricter cuts  $(x > 0.2, t > 5000 \text{ GeV}^2)$ . The solid lines describe the cross section of the vector and the dashed ones the cross section of the scalar. The standard model backgrounds to  $ep \rightarrow ec + any$  scattering amount to a few pb each for the first set and to somewhat under 0.1 pb each for the second set.

200-400 GeV is shown in more detail in Fig. 3(b). It is convenient to discuss separately the three mass ranges light (below HERA's kinematical limit), intermediate (above the kinematical limit and up to  $\sim 1.85$  TeV for the vectors and  $\sim 1.5$  TeV for the scalars), and heavy leptoquarks.

(i) The low-lying leptoquarks. The cross sections here are large and very enhanced relative to those of the heavier particles. This is because the leptoquark is really, and not only virtually, created in the machine. The propagator reaches the pole area and, consequently, the cross section is strongly enhanced. We therefore recommend that an  $eu \rightarrow ec$  signal be searched for if the x distribution of the cross section reveals the existence of a light leptoquark.

(ii) Intermediate leptoquarks. The first, immediate conclusion is that the cross sections of virtual leptoquarks always drop to the 1-pb level or below it. Note in particular that the looser cuts are not useful here, since the corresponding backgrounds, being a few pb each, are considerably larger than the signal. We therefore use the stricter cuts for which the leptoquark signal is even smaller. Virtual leptoquarks will therefore not be discovered via their possible  $eu \rightarrow ec$  signal, unless the luminosity or charm identification methods are improved. We remark also that, above  $\sim 500$  GeV, the cross sections settle into constant, mass-independent, values. This is due to the fact that for such heavy leptoquarks the propagators that appear in the cross-section formulas are essentially identical to those that appear in the low-energy bounds. Saturation of the bounds then eliminates the mass dependence of the cross sections.

(iii) Heavy leptoquarks. Here the cross sections start dropping as the mass grows. This is because we do not saturate the bounds but rather fix the coupling constant at  $g^2=4\pi$ . The cross sections drop so rapidly that even if the luminosity or charm identification methods are improved, we do not expect to penetrate deeply into this region.

Our results for the charge  $\frac{5}{3}$  leptoquarks are presented in Fig. 4. The cross sections of the charge  $\frac{5}{3}$  virtual parti-



FIG. 4. Maximum  $ep \rightarrow ec + any$  cross sections for charge  $\frac{5}{3}$  leptoquarks with the two sets of cuts. Solid lines for the vector and dashed ones for the scalar.

cles are, within a factor of  $\sim 3$  of those of the corresponding charge  $\frac{1}{3}$  particles. We conclude that, like their charge  $\frac{1}{3}$  counterparts, charged  $\frac{5}{3}$  virtual leptoquarks will not be seen via  $eu \rightarrow ec$  scattering at HERA. Considering the possibility that there will be some improvement on the luminosity or on charm identification, we can see by studying Figs. 3 and 4 that it will become possible to penetrate the region of leptoquarks with masses up to 1.5-2 TeV if they have maximum couplings. The best prospects are for charge  $\frac{5}{3}$  vectors, then charge  $\frac{1}{3}$  scalars, then charge  $\frac{1}{3}$  vectors, and finally charge  $\frac{5}{3}$  scalars. We should stress again that the cross sections described in our figures are calculated with optimistic approach toward the actual values of the leptoquark widths and, more significantly, with the maximum allowed coupling constants, as drawn in Fig. 2. The cross sections of the virtual leptoquarks behave as  $g^4$ . If  $g^2$  is smaller by just a factor of 3 from the present bound, the  $eu \rightarrow ec$  signal of a virtual particle will never be seen in HERA.

Note that below HERA's kinematical limit, the cross sections of the charge  $\frac{5}{3}$  leptoquarks are considerably smaller than those of the charge  $\frac{1}{3}$  particles. This is because the cross section in this region is enhanced by the *s*-channel propagator. In the case of the charge  $\frac{1}{3}$  leptoquarks the *s* channel is in *eu* scattering, while in the case of the charge  $\frac{5}{3}$  particles it is in *eu* scattering. Since the proton is far richer in up quarks than in up antiquarks, the *s*-channel enhancement is more significant for the charge  $\frac{1}{3}$  leptoquarks.

Finally, we wish to remark on the cross sections for a possible  $eu \rightarrow \mu c$  signal. When this process was studied in [1], there was no experimental bound available on the leptoquark couplings. Today, in analogy to the case discussed in this paper, there are bounds coming from  $D^0 \rightarrow e\mu$  decay and inclusive  $c \rightarrow e\mu + any$  decay. Since the bounds on these processes are numerically very simi-

lar to the bounds on  $D^0 \rightarrow ee$  and  $c \rightarrow ee + any$ , we find that the maximum cross sections calculated in this paper are also relevant for the  $eu \rightarrow \mu c$  signal and therefore serve as an update on the results of [1].

In conclusion, we find that an  $eu \rightarrow ec$  signal will not enable us to see virtual leptoquarks at HERA, if the luminosity is 200  $pb^{-1}$  and charm identification efficiency is 1%. Some improvement (by factor of  $\sim 2$ ) on the luminosity or on charm identification may enable us to see virtual, charge  $\frac{5}{3}$  vector leptoquarks and charge  $\frac{1}{3}$  scalar leptoquarks up to masses of order 1.5-2 TeV. Further improvement (by another factor of  $\sim 2$ ) may let us see signals of charge  $\frac{1}{3}$  vector leptoquarks with similar masses. All this applies only if the leptoquarks couplings are near their bound. Otherwise, further improvement on luminosity and charm identification is necessary. Virtual charge  $\frac{5}{3}$  scalars leptoquarks will probably not be seen via an  $eu \rightarrow ec$  signal. While the case for virtual leptoquarks seems discouraging, the case for real leptoquarks (lighter than HERA's kinematical limit) is quite interesting. The cross sections for  $eu \rightarrow ec$ , particularly when mediated by a charge  $\frac{1}{3}$  leptoquarks, could be very large. Therefore, if a real leptoquark is discovered at HERA via a peak in the x distribution of the cross section, it may well be worth looking for an  $ep \rightarrow ec + any$ signal induced by it.

I thank Uri Karshon and Yehuda Eisenberg for telling me about their interest in investigating an  $eu \rightarrow ec$  signal at HERA, and for familiarizing me with various relevant experimental issues. Uri Karshon also provided me with the estimates for the photon-gluon fusion background. I am grateful to Arie Shapira for discussions on the experiment and to Yossi Nir and Shmuel Nussinov for many interesting discussions on the theory.

- [1] I. I. Bigi, G. Köpp, and P. M. Zerwas, Phys. Lett. 166B, 238 (1986).
- [2] Y. Eisenberg, U. Karshon, and A. Montag, in Proceedings of the Workshop on Physics at HERA, Hamburg, Germany, 1991, edited by W. Buchmuller and G. Ingelman (unpublished), p. 1147.
- [3] Particle Data Group, J. J. Hernández et al., Phys. Lett. B 239, 1 (1990).
- [4] P. M. Zerwas (private communication via Y. Eisenberg).

- [5] O. Shanker, Nucl. Phys. B204, 375 (1982).
- [6] W. Buchmüller and D. Wyler, Phys. Lett. B 177, 377 (1986).
- [7] W. Buchmüller, R. Rückl, and D. Wyler, Phys. Lett. B 191, 442 (1987).
- [8] P. Haas et al., Phys. Rev. Lett. 60, 1614 (1988).
- [9] A. J. Weir et al., Phys. Rev. D 41, 1384 (1990).
- [10] E. Eichten, I. Hinchliffe, K. Lane, and C. Quigg, Rev. Mod. Phys. 56, 579 (1984); 58, 1065(E) (1986).